GUIDELINES FOR STABILIZING PROBLEMATIC SOILS USING CALCIUM-BASED STABILIZERS PROPOSAL

by

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PROBLEM STATEMENT

The main goal of the proposed project is to establish protocols for conducting efficient chemical stabilization design for problematic soils with and without soluble sulfates within the state of Montana. The Montana Department of Transportation has very limited experience with chemical stabilization, and while there is a desire to potentially use chemical stabilization, a major concern with this approach is the presence of potential high sulfate concentrations and costs incurred in undertaking chemical stabilization projects. This proposal aims at addressing these issues by conducting laboratory studies to determine effective chemical stabilizers for stabilizing Montana specific problematic soils. In addition, this project will also perform life cycle cost analysis in order to compare and contrast existing approaches vs chemical stabilization alternatives in tackling these problematic soils.

A major portion of chemical stabilization protocols involves the selection of type and amount of the additives. The proper selection of type and concentration of additive for a given soil should consider, the complex interactions between the mineralogy of the materials and additives, the presence or absence of moisture, and the method of construction and curing. If the selected concentration of additives is not adequate to ensure short- and long-term durability of a pavement layer, costly pavement rehabilitations will be needed. As part of this project, testing methods will be proposed that account for soil specimen preparation, curing, conditioning and testing time to explain whether the stabilizer or stabilization is deemed to be effective in real field environment. These test procedures will mimic field conditions as much as feasible in terms of soil particle gradation, sample compaction, moisture susceptibility and curing.

BACKGROUND SUMMARY

Introduction

Chemical soil stabilization has been a topic of interest and discussion for several decades (Tayabji, et al., 1982) due to potential reduction in the construction and maintenance costs of pavement infrastructure built on problem grounds. Extensive research was documented with regard to the engineering properties, reliability and durability of various types of stabilized materials (Little, 2000; Little and Nair, 2009; Pedarla et al. (2011); Wen et al. 2014; Chittoori et al. 2014). This section of the proposal reviews the available literature on various soil stabilization methods and existing design protocols from state and federal agencies.

Soil stabilization is the process of improving engineering behavior of a soil by changing one or more properties of the soil. In essence, it is the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil (Haussman, 1982). The main properties that are typically altered by stabilization are:

- Shear strength – ability to resist shear stresses developed as a result of traffic loading
- Modulus (stiffness) – ability to respond elastically and minimize permanent deformation when subjected to traffic loading
- Resistance to moisture – the ability to resist the absorption of water, thus maintaining shear strength and modulus, and decreasing volumetric swell (in case of expansive soils)
- Stability – the ability to maintain its physical volume and mass when subjected to load or moisture (in case of expansive soils)
- Durability – the ability to maintain material and engineering properties when exposed to environmental conditions such as moisture and temperature changes.

In case of pavements, they are usually designed based on the assumption that specified levels of quality will be achieved for each soil layer in the pavement system. Each layer must resist shearing within the layer, avoid excessive elastic deformations that would result in fatigue cracking within the layer or in overlying layers, and prevent excessive permanent deformation through densification. When the quality of a subgrade layer is improved, its ability to distribute the load over a greater area is generally increased enough to permit a reduction in the required thickness of the overlying layers. Generally, the soil quality improvements through stabilization include, better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and strength.

Different Forms of Chemical Stabilization

Chemical stabilization can be brought about in three ways:

- Bonding the soil particles together: In this, soils are stabilized by cementing the particles together so that the effect of water on the structure is lessened.
- By waterproofing: In this the soil moisture content is maintained at low level at which it has adequate strength for the intended purpose.
- By a combination of both waterproofing and bonding

A basic understanding of how each additive works as well as the impact of soil properties on the selection of type and concentration of additive should be considered during chemical stabilization design. Coating particles, binding particles together, and formation of new compounds are the main mechanisms that can occur when using an additive (Army TM 5-822-14, 1994). The degree and speed of the mechanism depends on the composition of the additive and the material being treated.

Some additives work independently, while others require water or water plus silica and alumina present in clays. The mineralogy, quantity, and particle size of fines in the soil or base can greatly impact the performance of individual additives. The goal of the soil or base treatment and the additive mechanism, composition, and reaction time must all be considered when selecting the best additive for a specific application. A brief description of the three most common additives used in stabilization is presented in the subsequent sections.

Lime

Lime is formed by the decomposition of limestone at elevated temperatures. When lime is combined with water and the soluble silica and alumina is present in clay, a chemical reaction occurs, resulting in the formation of new compounds. When combined with water, its primary function is alteration of particle structure and increased resistance to shrink-swell and moisture susceptibility. A secondary result is binding of particles (when combined with clay) and strength gain. Since alteration of particle structure occurs slowly, depending upon the type of clay present, a mellowing period from 1 to 4 days is allowed to obtain a homogeneous, friable mixture.

Many researchers have used lime as a stabilizer with appreciable amount of success. Lime stabilization is a widely used means of chemically transforming unstable soils into structurally sound construction foundations. Lime stabilization enhances engineering properties in soils, including improved strength; improved resistance to fracture, fatigue, and permanent deformation; improved resilient properties; reduced swelling; and resistance to the damaging effects of moisture. The most substantial improvements in these properties are seen in moderately to highly plastic clays (Little, 2000).

Cement

Hydraulic cement is a product manufactured to meet a variety of performance criteria by controlling the relative proportions of calcium, silica, alumina, and iron compounds. When combined with water, hydration occurs, resulting in the formation of new compounds, most of which have strength-producing properties. When mixed with soil or base materials, particles become bound together and the mixture increases in strength and has high moisture resistance. Depending on the composition of the cement and the soil mineralogy, a chemical reaction can occur between calcium hydroxide and the soluble silica and alumina present in clay, resulting in alteration of particle structure and increased resistance to shrink-swell.

Cement has been found to be effective in stabilizing a wide variety of soils, including granular materials, silts, and clays; byproducts such as slag and fly ash; and waste materials such as pulverized bituminous pavements and crushed concrete. These materials are used in pavement base, subbase, and subgrade construction (Little et al., 2000). It is generally more effective and economical to use it with granular soils due to the ease of pulverization and mixing and the smaller quantities of cement required. Fine-grained soils of low to medium plasticity can also be stabilized, but not as effectively as coarse-grained soils. If the PI exceeds about 30, cement becomes difficult to mix with the soil. In these cases, lime can be added first to reduce the PI and improve workability before adding the cement (Hicks, 2002). Cement stabilization develops from the cementitious links between the calcium silicate and aluminate hydration products and the soil particles (Croft, 1967). Addition of cement to clay soil reduces the liquid limit, plasticity index and swelling potential and increases the shrinkage limit and shear strength (Nelson and Miller, 1992).

Fly Ash

Fly ash is a by-product of coal combustion and its components vary depending upon the specific coal combustion process. Class F is a pozzolan that often requires an activator such as lime or cement. Class C is a combination of a pozzolan and self-setting material. When combined with water, a cementitious reaction occurs, which results in binding of particles together. Depending on the chemical composition, alteration of particle structure and increased resistance to shrink-swell and moisture susceptibility can occur.

Fly ash is defined in Cement and Concrete Terminology (ACI Committee 116) as "the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases." Fly ash is a by-product of coal-fired electric generating plants. Two main types of fly ash are being used: non self-cementing Class F and lime-fly ash self-cementing Class C. Stabilization of soils and pavement bases with coal fly ash is an increasingly popular option for design engineers. Fly ash decreases swell potential of expansive soils (Ferguson 1993, White et al. 2005). Soils can be treated with self-cementing fly ash to modify engineering properties as well as produce rapid strength gain in unstable soils.

Secondary stabilizers

These are the stabilizers which are not effective when used solely, but are effective when used with another primary stabilizing agent such as lime or cement. Examples of secondary stabilizers include blast furnace slag, cement kiln dust, lime kiln dust and others.

Review of current stabilization procedures

A review of the literature has been carried out in order to outline current state of practice and stabilization guidelines followed by agencies such as Texas Department of Transportation (TxDOT), the US Army and Air Force, Portland Cement Association, National Lime Association, ASTM Standards, and other relevant researches available, either nationally or worldwide. The most significant studies found are summarized in the following sections. A good summary from several highway agencies was found in TENSAR technical note (1998), including examination of engineering properties, discussions of design, construction and economics for lime, cement and fly-ash stabilization, where soft subgrades are encountered in construction. According to Army and Air force stabilization manual (Army TM 5-822-14) the factors that must be considered for the selection of a stabilizer are, the type of soil to be stabilized, the purpose for which the stabilized layer will be used, the type of soil improvement desired, required strength and durability, and cost and environmental conditions.

Mix design is essential to optimize the material properties, calculate the right percent of additive, measure effectiveness and engineering properties and provide density and moisture control parameters for construction. TxDOT guidelines denote a few steps to achieve the mix design:

- ✓ Verifying that sulfate and organic contents are within acceptable limits,
- ✓ Developing moisture density curve (M/D) for field density control,
- ✓ Strength testing before and after moisture conditioning, and
- ✓ Determining the lowest modifier content to satisfy strength requirements.

Summary

Chemical stabilization of soils has been around for about 70 years now, primarily due to the reduction in the construction costs and improvement in the road surface performance. It is documented that the success of a chemical stabilization project depends on factors such as:

- ✓ Proper selection of type of stabilizer based on appropriate material type
- ✓ Proper selection of additive dosage that gives adequate short-term and long-term strength
- ✓ Proper compaction of the stabilized soil at specified density and moisture conditions
- ✓ Appropriate construction methods to ensure effective implementation.

The performance of chemical stabilization depends on the interactions between the chemical additive and the soil minerals. There is a wide array of chemicals available for stabilization which include Lime, Cement, Fly ash, Cement Kiln Dust, among others. It is important to evaluate these chemicals for some Montana specific soils and develop guidelines for their use. In addition, special considerations need to be made in case of soils with high sulfate concentrations as these lead to sulfate-induced heaving where an expansive mineral called Ettringite is formed.

BENEFITS AND BUSINESS CASE

The stabilization design protocols developed as a part of this project can help MDT more effectively determine if chemical stabilization is a viable method for Montana specific soils, particularly in the Great Falls and Glendive districts where clay soils are very common.

By conducting this research MDT will invest in gaining the much needed knowledge in chemical stabilization of problematic soils specific for Montana. This research will also help quantify the necessary resources (i.e. investigation frequency, lab testing, design protocols) that would be required to effectively assess whether chemical stabilization can be incorporated at MDT with an acceptable level of risk on a wide spread approach while considering the existing resources.

Potential savings of using chemical stabilization in place of conventional methods that involve extensive repair and reconstruction cannot be recognized unless this research is conducted.

OBJECTIVES

Specific research objectives of this proposal are

1) Determine effectiveness of common soil stabilizing agents for mitigating problematic Montana soils
2) Develop protocols and specifications for selection of additive type and dosage.
3) Understand sulfate heaving issues and shed light on factors such as soil fabric, additive types along with reactive alumina and silica.
4) Examine scope and impact of using stabilizing agents to mitigate problematic soils against current MDT practice.

RESEARCH PLAN

The goal of this project is to develop a comprehensive guideline for effectively and in an accelerated manner evaluate the suitability and concentration of additives. To address the objectives enumerated above, and to optimize the deliverables given the funding constraints, a two-year study is proposed with the following task plan.

Task 1. Current Practices Survey

A substantial review of literature has been carried out during the preparation of this proposal. We have already identified substantive work in this area funded recently by agencies such as Texas Department of Transportation (TxDOT), Colorado Department of Transportation (CoDOT) and other agencies throughout the Unites States and the world.

In this task, we will conduct another information search to study and evaluate the various studies undertaken in surrounding states (North Dakota, South Dakota, Idaho and Wyoming) and in Canada (Saskatchewan region) to stabilize problematic soils like expansive soils, soft clays, loose sands etc. We will keep the focus on the problematic soils encountered in Montana. This literature review will also inform us about the type of soils to be selected for task 2 of this study. In order to effectively perform this task, especially due to unpublished practices which are hard to find via any database search, we propose to perform a survey of practices related to problematic soils in various state agencies in the above mentioned states. The focus of this survey will be toward identifying the lab and field methods proposed for chemical and physical characterization of the stabilized materials, the design considerations given to these types of treatments, and methods for accelerating the curing and moisture conditioning of subgrades and bases. The technical panel will review survey questions and provide input on distribution before survey is sent out.

The results of this task will be summarized in a concise manner and will be reported to the Technical Panel (TP) through a task report.

Task 2. Material Selection

The selection of materials for this project will be performed with consultations with TP using the newly developed GIS map that can better quantify areas of the state where higher sulfate levels are known to exist along with locations of other problematic soils. In addition to the map the research team with the help from the TP will develop a questionnaire and distribute it state-wide to understand the extent of the problem, locate the districts that perceive that they can benefit from the outcome of this study. In this questionnaire we will also identify any experimental or full-scale sections that the districts have constructed and how they perceive the performance of those sections.

Based on the interaction with the districts and the TP, six materials will be selected for observation and as a baseline for verification of the outcome of this study. The goal is to obtain different material types from various environmental conditions for the development of stabilization guideline and treatment for sulfate-rich soils. Preliminary, these soils could consist of three high-plasticity clays (with or without excessive sulfates), two low PI-clays, and a sandy subgrade. We will coordinate this selection process with the TP to ensure that the material selected is acceptable to them. We would also like to select the materials from areas that are close to an upcoming construction sites in case MDT will want to perform filed implementation.

The sampling locations will be decided after meeting with the technical panel (in-person or conference call). Once the locations are finalized, we will request MDT to perform sample collection using excavation equipment from the top few feet of ground surface. Care should be taken to avoid collecting top soil and any organics associated with it. We recommend that all soil samples be collected and stored in one central location in Montana. Once all samples are collected and after intimation to Boise State personnel. Boise State personnel will make a trip to Montana to collect all soil samples. Ideally we would like to make one trip, however, we will be prepared for three trips to accommodate logistics and deadlines.

Adequate amount of materials (200 to 300 pounds per site) will be collected for laboratory studies, which are described in the next task. We will study three different additives, lime, cement and fly ash for this project. Laboratory grade additives will be purchased from commercial sources.

The results of this task will be summarized in a concise manner and will be reported to the TP of the project through a technical report.

Task 3. Evaluate Chemical Stabilizers

In this task, we will evaluate lime, cement and fly ash for each of the six soils and determine which additive best suits the soil and at what level. Main goal of this task is to establish a matrix of additive types and amounts for different soils tested in this research. This matrix which will assist in developing stabilizer selection guidelines based on soil type and application. The following describes various soil tests, chemical and mineralogical studies utilizing X-Ray Diffraction (XRD) and Scanning Electron Micrography (SEM) studies, and performance related laboratory tests on the proposed test soils:

A. **Conduct index tests** to determine the gradation, plasticity index or PI and soil classification.

B. **Select appropriate types of additives** following existing guidelines from other DOTs (most likely TxDOT)

C. **Conduct chemical and mineralogical analyses on soil specimens** to evaluate the clay mineralogy and the amounts of reactive alumina/silica and sulfates. (see Task 4)

D. **Determine appropriate concentration of additive** based on the following criteria (see Task 5):

    a. **Conduct triaxial or unconfined compressive strength tests** after curing and after moisture conditioning to determine if the material meets the strength requirements.

    b. **Conduct modulus tests** after curing and after moisture conditioning to determine if the material meets the stiffness requirements.

E. **Assess the permanency of the chemical stabilization** from moisture flows during rainfall events and to evaluate the durability of chemical treatments when subjected to wet-dry cycles. (see Task 6)

The results of this task will be summarized in a concise manner and will be reported to the TP of the project through a technical report.

Task 4. Establish Chemical and Mineralogical Changes in Mix Properties

Chemical species measurement tests and clay mineral related identification tests will be conducted on both the control and chemically-treated soils. Control soils are untreated soils selected from

Task 2. Chemically-treated soils are the same soils stabilized with additive and their dosages. The following steps provide descriptions of the chemical and mineralogical studies proposed in this study:

a) The soluble sulfate levels will be first determined as per the current AASHTO procedure with a minor modification to avoid using platinum crucible. If the sulfate sources are low soluble, then other sulfate measurement procedures will be conducted to determine soluble sulfates.

b) The reactive alumina and silica of both treated and untreated soils will be measured. Procedures established at the by Puppala et al. (2005) and Wattanasanticharoen et al. (2005) will be closely followed.

c) The dominating clay mineral in each of the soils selected will be established by following the method proposed by Chittoori and Puppala (2011). This method requires the determination of soils properties such as Cation Exchange Capacity, Specific Surface Area (SSA) and Total Potassium (TP) which will be conducted in Boise State's laboratories. These tests will be performed before and after treatments to evaluate the formation of pozzolanic compounds which are responsible for improvements in soil.

The results of this task will be summarized in a concise manner and will be reported to the TP of the project through a technical report.

Task 5 Establish Curing and Moisture Conditioning Protocols

As explained in task 3D, in order to determine appropriate concentration of the additive we will conduct strength tests (UCS or Triaxial) on cured and moisture conditioned soil specimens. There are several recommendations from various agencies on how to perform curing and moisture conditioning. In this task we will evaluate these methods and establish a protocol that best represents Montana field conditions and is not very time consuming. Some of the available alternatives are discussed as follows:

- ***Backpressure Saturation:*** In this method, the specimen is covered with a membrane, and placed in a triaxial chamber. The confining pressure and internal pressure of the specimen are independently controlled. Even though the confining pressure can be applied using air or water; the internal pressure is applied through a water reservoir after all lines are saturated. Both the internal and confining pressures are increased by the same amount first, and then the internal pressure is increased so that the water can be pushed through the specimen. The amount of the confining pressure and the difference between the confining pressure and the internal pressure dictate how fast the water can penetrate through the specimen and its ultimate saturation. The greater the difference between the internal pressure and the confining pressure is the faster the specimen will saturate. However, the bigger the difference is, the greater the hydraulic gradient within the specimen will be. High hydraulic gradients may cause damage to the internal structure of the specimen. These limits should be carefully studied to find the best compromise between the time of saturation, the damage to specimen and to the resemblance of the saturation condition to the field conditions. One other advantage of this method is that the degree of saturation of the specimen can be measured

  Submerging Specimen: Several organizations have advocated the submergence of the specimen to accelerate moisture conditioning for a given period of time. In principle, this may work for some materials. But this method would very harshly moisture-condition the coarse-grained materials, and would not be very effective for materials that have low permeability and/or high suction. For clayey materials, the specimen may have to be soaked for many days to weeks to be truly moisture-conditioned. This matter should be studied as well.

- ***Curing:*** It is well-known that the moisture regime and the temperature during curing will impact the ideal strength and stiffness of a given stabilized materials. A higher curing temperature accelerates the progress of lime-soil reactions when lime additions are above the Lime Modification Optimum or LMO values. Also, pozzolanic activity commences after 1 day of curing at 72°F or 25°C and the same needed 7 days curing at a low temperature of 11.5°C. These suggest that strength development from pozzolanic activity will occur more quickly in hot semi-arid climatic zones than in cool temperature zones (Rao and Shivananda, 2005).

  Through a factorial design we will attempt to address this issue. The specimens will be cured at room temperatures of 72°F, and at other appropriate temperatures depending on the additives (e.g. 90°F and 110°F for cement), and full moisture access with and without membrane around the specimens to determine how much the curing can be accelerated.

The results of this task will be summarized in a concise manner and will be reported to the TP of the project through a technical report

Task 6. Evaluating Long-term Durability of Stabilization

Another moisture conditioning study is proposed here to address both permanency of chemical stabilizer and durability of chemical treatment after undergoing wet and dry cycles. The PI was recently involved in this type of research for addressing the performance of novel stabilizers for modifying sulfate-rich soils in Texas. Experience gained from these investigations will be utilized to develop two modified protocols based on the current standards of practice. An attempt will be made to ensure these tests do not run longer than seven day period. ***It should be mentioned that if the back-pressure saturation method in Task 5 is found feasible and implementable, the following two methods can be integrated with it.***

The goal of this task is to analyze the effectiveness and permanency of chemical stabilization of problematic soils under cyclic durability studies, consisting of both wetting/drying and leachate studies, performed in laboratory conditions. Wetting/Drying cycles and leachate collection are typically conducted as separate tests, though in reality these two testing conditions occur simultaneously in the field. Hence, it is important to consider both aspects of durability studies occurring simultaneously on a singular soil specimen to further understand how the presence of water effects chemically stabilized soil. Therefore, the primary goal of this task is to develop a test protocol that address these aspects of chemical stabilization. This test protocol will address the permanency of the chemical stabilization from moisture flows during rainfall events, ground water flows and moisture migration from suction and head differences. This test will utilize a flexible wall mold housing the compacted stabilized soil specimen. This setup was fabricated by the PI at the University of Texas of Arlington during PI’s PhD work. A similar device will be made here at Boise State and an attempt will be made to simulate the flow scenario close to Montana conditions.

The compacted soil specimen will be subjected to moisture flow from a water tank at a constant pressure. A few preliminary tests will be conducted to finalize the pressures to be applied to the water flow. Moisture flow through the specimen can be varied in both directions, and moisture samples will be collected after each complete leaching cycle (the amount of flow should be equal to one soil specimen void volume). Several leaching cycles tests will be performed on present chemical treated soil samples and the water samples will be collected from the soil sample after each cycle.

Water samples collected will be subjected to pH as well as chemicals such as free calcium, alumina and sulfate measurements. Results will be statistically analyzed to address loss of stabilizer due to leaching. An attempt will be made to correlate leaching cycles with field moisture movements from rainfall events. Hence, the final outcome of these leachate tests is the development of a reliable procedure to address the leaching and permanency aspects of chemical treatments.

Another important aspect of this test is to address the durability of chemical treated soils by exposing treated soil samples to various cycles of freezing and thawing processes. During these processes, both volume change and soil strength and stiffness can be determined. These determined properties will provide insights into the effects of seasonal moisture fluctuations on the soil property variations. The PI was involved in wetting and drying tests on chemical treated soils in a special setup (see Figure 1). An attempt will be made to revise this procedure to reflect both wet/dry and freeze/thaw conditions close to Montana conditions in a reasonably short time period of seven to fourteen days. Thus a modified procedure will be formulated. Suggestions and input from TP will be sought and followed in the final formulation of the test protocol. The protocol will be followed to conduct tests on the stabilized soils and the number of cycles during the procedure will be varied. At the end of each cycle, volume change and moisture content measurements will be made. After certain cycles, the specimens will be subjected to strength measurement studies using unconfined compression strength tests and mineralogical studies using XRD.

Test data collected will be analyzed to address soil property changes due to wet and dry cycles and freeze and thaw cycles, stabilizer reactions and variations in the peak intensities of stabilizing compounds from the XRD data. The final outcome of this task will be complete assessments of chemical stabilizers in providing durable treatments of pavement subgrades without being affected by the moisture leaching and seasonal moisture fluctuations.

The results of this task will be summarized in a concise manner and will be reported to the TP of the project through a technical report.

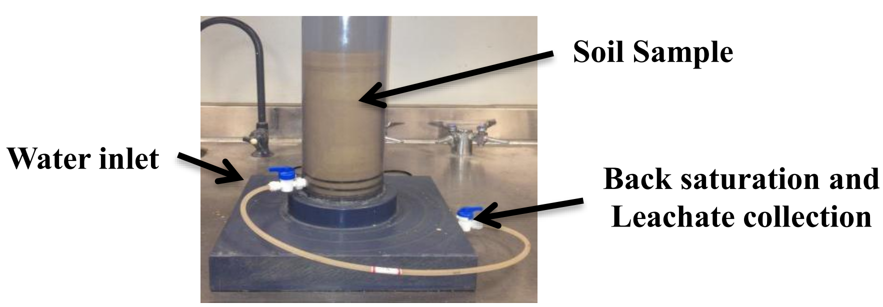

Figure 1 Durability Setup for the Proposed Research

Task 7. Life Cycle Cost Analysis

One of the objectives of this project is to help engineering managers in making informed decisions on adopting appropriate methods in handling problematic soils. Towards this goal, in this task the current MDT practices in handing problematic soils will be compared to chemical stabilization alternatives on a life cycle cost basis. This will enable engineers to make informed decisions on selection of appropriate design alternative. While performing this analyses NCHRP guidelines to conduct life cycle cost analysis will be closely followed.

Task 8. Develop Guidelines and Protocols

Upon completion of the first six tasks, including a review of the performance of the existing sites in Montana, a preliminary protocol for lab testing will be developed.

We propose close interaction through several meetings between the research team and the TP to evaluate the practicality and validity of the technical aspects, and to ensure that the institutional aspects are fully-considered. We propose one in-person meeting and one conference call. During the in-person meeting Boise State personnel will make a presentation on the proposed protocol and seek input from the TP. After this meeting we will make modification as per the input and organize a conference call to discuss the changes and steps forward.

At a minimum the guideline will contain the following:

- the appropriate type and concentration of additives given the type and environmental condition of the site
- the ideal and retained strengths and moduli
- the chemical and mineralogical properties of the mix
- the long-term durability in terms of moisture susceptibility, and retention of stabilizers

The results of this task will be summarized in a concise manner and will be reported to the TP in the final report.

MDT INVOLVEMENT

Interaction between Boise State and MDT is required to ensure that the protocols and procedures developed are consistent with MDT directions.

Assistance with sample collection from the field in terms of providing equipment, traffic control and sample delivery is also anticipated. The sampling locations will be decided after meeting with the technical panel (in-person or conference call). Once the locations are finalized, we will request MDT to perform sample collection using excavation equipment from the top few feet of ground surface. Care should be taken to avoid collecting top soil and any organics associated with it. We are anticipating collecting about 200 to 300 pounds of soil per sampling location. We recommend that all soil samples be collected and stored in one central location in Montana. Once all samples are collected and Boise State is intimated, Boise State personnel will make a trip to Montana to collect all soil samples. Ideally we would like to make one trip, however, we will be prepared for three trips to accommodate logistics and deadlines.

PRODUCTS

The following products will be submitted to MDT in a timely fashion:

- Progress reports – Monthly
- Task reports
    - At the end of task 1,
    - At the end of tasks 2 & 3 (combined)
    - At the end of task 4
    - At the end of tasks 5 &6 (combined), and
    - At the end of task 7
- Matrix of tested soils, additive types and contents
- Durability device
    - User manual
    - Equipment specifications
    - Test protocols
- Meeting notes
- Final presentation
- Final report, with cover photo
- Project summary report
- Implementation meeting report
- Technical design manual
- Performance measures report (includes both qualitative and quantitative performance measures, as appropriate)

IMPLEMENTATION

The products of the proposed research will be new procedures that can be readily implemented by the districts, in terms of the laboratory practices and design processes. A Technical Design Manual that establishes evaluation standards to select stabilization methods on consistent criteria, methods of evaluating the effectiveness of stabilization, methods for moisture conditioning of samples to evaluate the effectiveness of stabilization will be provided. Also a comprehensive guideline for conducting lab tests to determine the effectiveness of the stabilizers will be provided.

The implementable products consist of training-oriented presentation at annual construction and transportation conferences, a design manual to be distributed to all district pavement and construction engineers, and materials that can be used to update the pavement design manual.

SCHEDULE

Overall schedule of the project is presented in Table 1. This schedule includes the monthly or quarterly research reports as required by MDT. In addition, table presents detailed and fully itemized project cost for the state fiscal years by task.

Table 1 Project schedule along with fully itemized project cost for the state fiscal years by task

Research Activity		Estimated % of Total Budget	FY 2017												FY 2018												FY 2019											
			Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Kick-off Meeting																																						
Task 1	Current Practice Survey+	15%																																				
Task 2	Material Selection *	5%																																				
Task 3	Evalaute Chemical Stabilizer+	10%																																				
Task 4	Establish Chemical and Minera Changes in Mix Properties*	10%																																				
Task 5	Establish Curing and Moistu Conditioning Protocols*	20%																																				
Task 6	Long-Term Durability Studie+	20%																																				
Task 7	Life Cycle Cost Analysis+	10%																																				
Task 8	Develop Guidelines and Protoc+	10%																																				

*Expected travel/meeting +Deliverable

BUDGET

The total budget for this project is $152,698. The budget includes salary support for the PI (2.5 months), one undergraduate researcher (12 months) and one graduate research assistant (24 months). Tuition support for the graduate student is also included in the budget. An amount of $3,000 is allocated for report editor who will edit the final report as well as intermediate technical reports. We will use materials cost of $4,800 for purchasing the required additives for stabilization and other supplies for laboratory tests described in tasks 3, 4, 5 and 6. Other direct costs include travel support of $5000. Travel support will facilitate researchers to make visits to Montana during sample collection and project meetings including kick-off meeting. Members of the research team will make trips to Montana for meetings (including kick-off meeting), sample collection and for project presentations. The research team envisions that six such trips (one kick-off meeting, three sample related, two project presentations) will be made during the two years of the project (two research team members will travel each time). The estimated costs per trip are as follows:

Travel (Car rental): $200

Hotel (2 rooms x $100 per room per night x 1 night): $200

Per Diem and Misc. $200

Gas for Rental Car (500 miles one way): $200

Total Cost per trip ~: $800 (please note that even though 6 trips of $800 (each) amount to only $4800, we are requesting an additional $200 s a buffer)

The university overhead rate is 40.5%. An itemized budget for this project is presented in the Table 2. In addition, Table 3 presents an itemized budget as per state fiscal year.

Table 2 Itemized Budget

ITEMIZED BUDGET								
Budget Categories	**%**	**Mths**	**Year 1**		**Year 2**		**Total**	
Salaries								
PI-Chittoori		1.25	$	10,938	$	11,266	$	22,205
Report Editor		0.6			$	3,000	$	3,000
Graduate Student		12	$	18,000	$	18,540	$	36,540
Graduate Student			$	-	$	-	$	-
Undergraduate Student Academic Year		0	$	-	$	-	$	-
Undergraduate Student Summer		0	$	-	$	-	$	-
Post Doc		0	$	-	$	-	$	-
Research Technician		0	$	-	$	-	$	-
Undergraduate student		6	$	6,000	$	6,180	$	12,180
Total Salaries			**$**	**28,938**	**$**	**32,806**	**$**	**73,925**
Fringe Benefits		**%**						
PI-Chittoori		0.36	$	3,938	$	4,056	$	7,994
Report Editor		0.36	$	-	$	1,080	$	1,080
Graduate Student		0.04	$	720	$	742	$	1,462
Graduate Student		0.04	$	-			$	-
Undergraduate Student Academic Year		0.04	$	-			$	-
Undergraduate Student Summer		0.04	$	-			$	-
Post Doc		0.36	$	-			$	-
Research Technician		0.47	$	-			$	-
Undergraduate student		0.04	$	240	$	247	$	487
Total Fringe			**$**	**4,898**	**$**	**6,125**	**$**	**11,022**
O&E								
Materials and Supplies			$	3,000	$	1,500	$	4,500
Total O&E			**$**	**3,000**	**$**	**1,500**	**$**	**4,500**
Travel								
In State Travel							$	-
Out of State Travel			$	2,500	$	2,500	$	5,000
Foreign Travel			$	-	$	-	$	-
Total Travel			**$**	**2,500**	**$**	**2,500**	**$**	**5,000**
Student Costs								
Graduate Student Fee Remission			$	10,000	$	10,000	$	20,000
							$	-
Total Student Costs			**$**	**10,000**	**$**	**10,000**	**$**	**20,000**
Total Direct Costs			$	49,336	$	52,931	$	114,447
Base for Indirect Calculation			$	39,336	$	42,931	$	94,447
Indirect Costs (F&A) MTDC	**40.5%**		$	15,931	$	17,387	$	38,251
Total Costs			$	65,267	$	70,318	$	152,698

Table 3 Itemized Budget as per State Fiscal Year

STATE FISCAL YEAR BASED BUDGET						
			Fiscal Year			
Budget Categories	**%**	**Mths**	**March 2016-June 2016**	**July 2017-June 2018**	**July 2018-June 2019**	**Total**
Salaries						
PI-Chittoori		1.24	$ 11,181	$ 11,516	-	$ 22,697
Report Editor		0.6	$ -	$ -	$ 3,000	$ 3,000
Graduate Student AY & Summer		5	$ 7,500	$ 18,500	$ 10,500	$ 36,500
Post Doc		0	$ -	$ -	$ -	$ -
Research Technician		0	$ -	$ -	$ -	$ -
Undergraduate student Summer		5	$ 5,000	$ 6,259	$ 1,000	$ 12,259
Total Salaries			**$ 23,681**	**$ 36,275**	**$ 14,500**	**$ 74,456**
Fringe Benefits		**%**				
PI-Chittoori		0.37	$ 4,137	$ 4,261	$ -	$ 8,398
Report Editor		0.42	$ -	$ -	$ 1,260	$ 1,260
Graduate Student AY & Summer		0.07	$ 525	$ 1,295	$ 735	$ 2,555
Post Doc		0	$ -	$ -	$ -	$ -
Research Technician		0	$ -	$ -	$ -	$ -
Undergraduate student Summer		0.10	$ 500	$ 626	$ 100	$ 1,226
Total Fringe			**$ 5,162**	**$ 6,182**	**$ 2,095**	**$ 13,439**
O&E						
Materials and Supplies			$ 2,000	$ 1,500	$ 1,000	$ 4,500
Total O&E			**$ 2,000**	**$ 1,500**	**$ 1,000**	**$ 4,500**
Travel						
In State Travel						$ -
Out of State Travel			$ 1,500	$ 2,500	$ 1,000	$ 5,000
Foreign Travel			$ -	$ -		$ -
Total Travel			**$ 1,500**	**$ 2,500**	**$ 1,000**	**$ 5,000**
Student Costs			2.5 mos	full yr	1 semester	
Graduate Student Fee Remission			$ 2,344	$ 8,862	$ 4,653	$ 15,859
						$ -
Total Student Costs			**$ 2,344**	**$ 8,862**	**$ 4,653**	**$ 15,859**
Total Direct Costs			$ 34,687	$ 55,319	$ 23,248	$ 113,254
Base for Indirect Calculation			$ 32,343	$ 46,457	$ 18,595	$ 97,395
Indirect Costs (F&A) MTDC	**40.5%**		$ 13,098	$ 18,815	$ 7,531	$ 39,444
Total Costs			$ 47,785	$ 74,134	$ 30,779	$ 152,698

STAFFING

Dr. Chittoori will lead this project. Dr. Chittoori has been conducting research on swell and shrinkage behavior of soils, unsaturated soil studies on untreated and stabilized expansive soils, deep mixing stabilization studies, pavement material characterization studies and pavement and site instrumentation studies. He was involved in various soil stabilization projects that involved sulfate bearing soils. He has published extensively on soil characterization and stabilization related topics. He was involved in projects with DOTs like TxDOT during his PhD and postdoctoral work at The Universtity of Texas at Arlington and he is currently working ITD on three separate projects (one as PI and two as Co-PI). He developed the method proposed in this research to determine the dominant clay mineral in a given soil. During his PhD work, he also helped TxDOT revise their stabilization design guideline to make it less time consuming and more in line with field conditions. The experience gained from past and current research projects involving expansive soil characterizations and unsaturated soil mechanics will be valuable in fulfilling the proposed research objectives.

One graduate student and undergraduate students will work on this research with PI Chittoori on the laboratory tasks listed above. These students will have the necessary background to perform the tasks and will be trained by the PI. A table showing the number of person-hours devoted to each task by research team members is illustrated in Table 3.

Table 3 Project Staffing

Name of Principal Professional, Employee, or Support Classification	Role in Study	Task Hours									% of Time - Total Project Hours	% of time - Annual Basis
		1	2	3	4	5	6	7	8	Total		
Prof. Chittoori	Principal Investigator	30	30	30	30	30	30	30	30	240	7%	12%
Graduate Student	Laboratory Testing	300	200	300	300	400	400	80	100	2080	60%	100%
Undergraduate Student	Laboratory Testing	0	10	200	200	300	300	50	0	1060	30%	51%
Editor	Report editing and review	10	5	10	10	10	10	10	40	105	3%	5%
Total		340	245	540	540	740	740	170	170	3485	N/A	N/A

FACILITIES

The Boise State Civil Engineering Department maintains three laboratory spaces in the Environmental Research Laboratory and the Harry W. Morrison Engineering Laboratory (HML) building dedicated to geotechnical and transportation engineering materials testing. The HML building (1603 m^2) houses two machine shops, a high-bay facility, and research and teaching laboratories for the departments of Civil Engineering, Mechanical & Biomedical Engineering and Materials Science & Engineering. Standard equipment currently available include: sieve shakers, Proctor molds, Atterberg Limit set-up, Consolidometers, and Los Angeles abrasion set-up.

Dr. Chittoori's (PI) laboratory includes standard laboratory facilities such as fume hood with acid and solvent storage cabinets, bench space, and chemical storage accompanied by office space with computers and printer for student use. The lab houses a cyclic triaxial testing machine (Figure 2-left), which is capable of conducting static and dynamic triaxial tests along with resilient modulus testing on fine grained soils (10.2 cm diameter and 20.3 cm height specimen size). Also available, is an Atomic Absorption Spectrophotometer (Shimadzu AA 6800; Figure 2-right), which can determine elemental concentrations of various metals in organic and inorganic materials. The AA-6800 is designed and optimized to operate with a flame and graphite furnace and an ASC-6100 auto sampler is utilized for both flame and graphite furnace testing**.** In addition Dr. Chittoori is in the process of purchasing SASW-G (NDE 360) from Olson Instruments for performing the non-destructive testing in the test pit using Spectral Analysis of Surface Waves (SASW) method as discussed in task 6 of this proposal.

Figure 2: (left) Cyclic Triaxial Set-Up, (right) Atomic Absorption Spectrophotometer.

Major Field Equipment

Boise State University owns a 9600EC rig (Figure 3). The truck is equipped with a series of equipment for various size, drilling augers to standard penetration test, cone penetration test, piezocones, water-sampling probes, and continuous sampling tools. Different components of the system are as follows.

1) PowerProbe: The rig is equipped to a PowerProbe probe and associated tools.

2) SPT: The rig is equipped with standard penetrometer device along with the split sampling tools.
3) CPTu: The system is equipped to a CPTu (piezocone) system made by Envi Inc. (based in Sweden) to measure tip resistance, sleeve friction, and pore-water pressure.
4) The data acquisition (DAQ): is handled through a Geoprinter 60 (GP-60) system.
5) A multi-module CPT-pro program: designed for complex analysis, interpretation, and presentation of CPT soundings and elaborating geotechnical documentation.

Figure 3: Photographs showing the 9600EC rig

Large-Scale Testing Facility

Figure 4 shows a photograph of the testing pit in Boise State's HML lab. This pit is 1.8 m in diameter and 2.4 m in depth. This facility can be accessed using a truck which makes it convenient to drive the 9600EC rig next to the test pit for CPT testing. The laboratory has construction equipment available to handle soil placement, compaction, and excavation.

Figure 4: Large-scale test pit

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